Snow and Soil Moisture Contributions to Seasonal Streamflow Prediction

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Project Goal: The analysis aims to quantify, using a suite of state-of-the-art land surface models (LSMs), the relative contributions of snow information and soil moisture information to the accurate forecasting of streamflow at seasonal leads.

Project Description: Improved seasonal streamflow predictions have obvious benefits, helping water resource managers, for example, optimize reservoir operations and mitigate the destructive capacity of floods and droughts. Several climate mechanisms are potential contributors to skill in streamflow prediction. Western water managers rely heavily on snow observations to project post-snow-season water availability. A second potential contributor is the accurate forecasting of post-winter meteorological anomalies (precipitation and temperature) from wintertime climate conditions, particularly ocean temperatures. A third is knowledge of wintertime soil moisture contents below the snowpack: if the soil is dry below the snowpack, more of the spring snowmelt water may infiltrate the soil and later evaporate, whereas a wet soil below the snowpack may encourage greater streamflow and a more efficient filling of reservoirs. Here we quantify seasonal forecast skill associated with snow and soil moisture initialization using (i) multi-decadal naturalized streamflow measurements covering much of the western United States, (ii) a suite of state-of-the-art land surface modeling systems (the GMAO catchment, VIC, Noah, and Sacramento LSMs), and (iii) true forecast experiments.

The four models were integrated over the period 1920-2003 on a 0.5° grid covering CONUS using an hourly, observations-based, surface meteorological forcing data set. This 84-year simulation, labeled CTRL, provides a "maximum possible model performance" for comparison with our forecast experiments. Three prediction experiments (Exp1, Exp2, and Exp3) were then performed with each LSM, experiments designed to quantify the degree to which March-July (MAMJJ) streamflow can be predicted from January 1 conditions assuming no skill in the seasonal prediction of meteorological forcing. Exp1 consists of 84 separate 7-month forecasts (one for each year of 1920-2003) initialized on January 1 with the January 1 snowpack and soil moisture states produced by CTRL for the year in question. To represent a lack of knowledge of meteorological forcing during the forecast period, the LSM was integrated with the climatological seasonal cycle of diurnal forcing determined from the CTRL forcing files; thus, any skill generated in the forecast MAMJJ streamflows is attributable to the initialization alone. Exp2 is identical to Exp1, except that soil moisture was initialized with the climatological distribution of January 1 soil moisture; thus, in Exp2, no forecast skill was derived from soil moisture information – Exp2 relied solely on snow initialization for skill. Analogously, Exp3 is identical to Exp1, except that snow amounts were initialized to the climatological January 1 fields; thus, Exp3 relied solely on soil moisture initialization for forecast skill.

Results: Figure 1 shows the outlines of the 17 basins examined. For each experiment, the MAMJJ streamflows produced by each model were averaged across the grid cells within a basin and then combined into a single multi-model basin average. The average forecasts were evaluated against naturalized streamflow gauge data for the basin.

CTRL represents the best possible model simulation of observed streamflow because it makes use of both observations-based initial conditions and observations-based post-winter meteorological forcing. (CTRL thus does not consist of true forecasts.) Agreement between the CTRL results and the streamflow observations during the periods of overlap is presented in the top left panel of Figure 1. Agreement, or skill, is measured here in terms of the square of the correlation coefficient (r^2) between the observed time series of MAMJJ streamflows and the corresponding multi-model average time series. The r^2 values for CTRL vary from about 0.3 to 0.9, so while CTRL does capture 30-90% of the observed streamflow variance, this "best" simulation is not perfect, presumably due to deficiencies in the forcing and validation data and in the models.

The top right panel of Figure 1 shows the prediction skill obtained in Exp1, i.e., that obtained from knowing only the January 1 initial conditions. The r^2 values are reasonably large (up to ~ 0.5) and are generally significant at the 95% level. Thus, we see our first important result: the uncalibrated models predict, with some skill, observed streamflow months in advance without knowledge (beyond climatology) of meteorological conditions

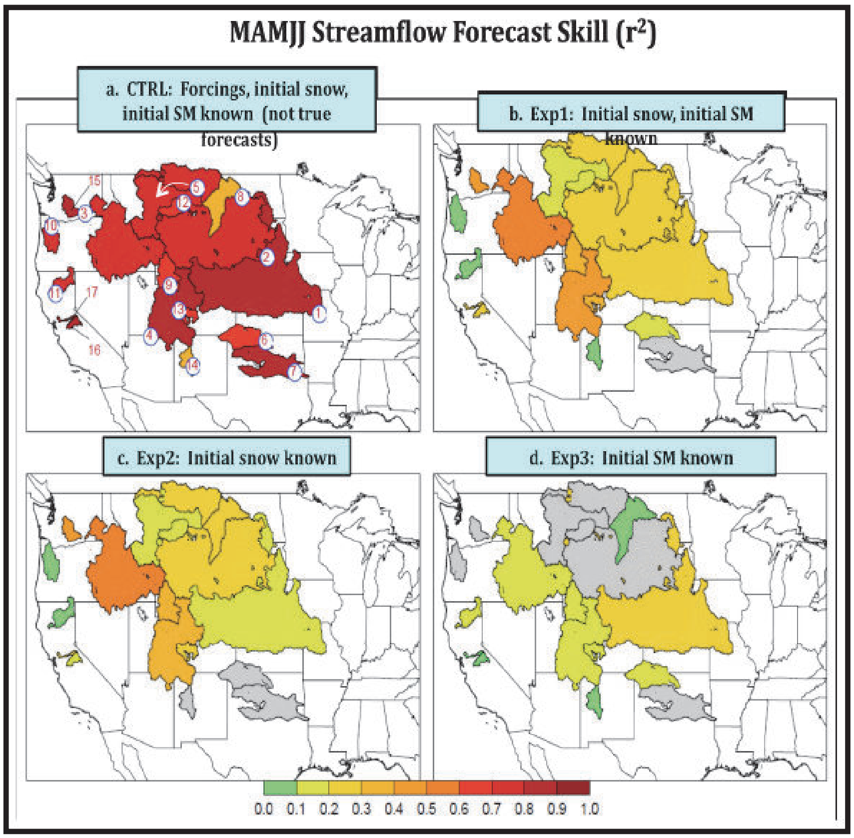

Figure 1: Streamflow skill levels, plotted by basin. a. CTRL, b. Exp1 forecasts (skill derived solely from knowledge of January 1 soil moisture (SM) and snow conditions), c. Exp2 forecasts, and d. Exp3 forecasts. Gray coloring indicates that a skill level is not significantly different from zero at the 95% confidence level.

The two bottom panels in Figure 1 show the skill metrics for Exp2 and Exp3. They show the isolated contributions of snow and soil moisture initializations to the streamflow forecast skill. Here we see our second important result: snow initialization is the dominant contributor to skill in most basins, particularly in the mountainous areas toward the northwest, whereas soil moisture initialization contributes significantly to skill in many basins, particularly toward the southeast (e.g., at gauges along the Colorado and Arkansas Rivers). In some of the southeastern basins, soil moisture contributes more to skill than snow does.

Figure 1 demonstrates that the initialization of snow and soil moisture on January 1 contributes skill to forecasts of MAMJJ streamflow across a broad sampling of western U.S. basins. Today's state-of-the-art land surface models, without calibration, are thus at a level of maturity suitable for transforming soil moisture and snowpack information into skillful streamflow forecasts. The study speaks to the potential value of improved snow and soil moisture observations, e.g., through space-based sensors (GPM, SMAP).

Publication

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